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Treatment of aortic arch aneurysms with a modular transfemoral multibranched stent-graft: Initial experience

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Objective: To present an initial experience with a new modular transfemoral multibranched stent-graft for treating aortic arch aneurysms.

Methods: Six patients, considered high risk for open surgery, were treated with a cu[illegible]n-m[illegible]branched stent-graft. Two patients had aortic arch aneurysms, three had descending thoracic aorti[illegible]eurysms i[illegible]lving the distal arch, and one had a saccular aneurysm of the arch adjacent to the origin of the ini[illegible]nate arte[illegible]. All patients had undergone a staged left carotid subclavian bypass before the endovasc[illegible] procedu[illegible]. Ea[illegible]branched graft had a 12-mm side branch for the innominate artery and an 8-mm side br[illegible]h for t[illegible]left co[illegible]on carotid artery. The branches were extended into their respective target arteries with c[illegible]ed [illegible]-expanding stents.

Results: Aneurysm exclusion without endoleak was successful[illegible] of the [illegible], and 11 of the 12 target vessels were successfully cannulated and preserved. Patient [illegible] loped a typ[illegible]ndoleak that was managed successfully with coiling and gluing of the aneurysm sac. P[illegible]tients [illegible], 5, and 6 had uneventful placement of the prostheses, with successful exclusion of the aneurys[illegible]. In patien[illegible]cannulation of the innominate branch was unsuccessful, and an extra-anatomic bypass was[illegible]cessary to perfuse t[illegible]e right carotid and vertebral arteries.

Conclusions: We have demonstrated the technical f[illegible]ibility of [illegible]odular transfemoral branched stent-graft for treatment of aortic arch aneurysms. Our initial expe[illegible]ce has [illegible]wn that the method is relatively safe. Long-term follow-up is necessary to evaluate t[illegible]fficacy an[illegible]of this new device. (J Thorac Cardiovasc Surg 2013;145:S110-7)

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Several methods have been proposed [illegible]t the i[illegible]sive-ness of aortic arch aneurysm repai[illegible]d red[illegible]e the m[illegible]bid-ity associated with hypothermic [illegible]ulat[illegible]st. Hybrid aortic arch procedures, end[illegible]asc[illegible]ortic [illegible] repair with fenestrated stent-gra[illegible]and in si[illegible]nestrations, and double-barreled techni[illegible]s[illegible]e all been [illegible]roduced as alternative treatment options fo[illegible]naging aortic arch pathologic findings. C[illegible]rall, the resu[illegible]of hybrid aortic arch procedures ha[illegible]been [illegible]isfactory; however, the associated mortality an[illegible]orbi[illegible]ty rates have not been negligible.[1] Clear indicatio[illegible]d the [illegible]ct role of hybrid repair have not b[illegible]n e[illegible]ned. [illegible]i[illegible]ressive experience has been de-v[illegible]ped in [illegible]pan with [illegible]enestrated stent-grafts[3]; and the re-su[illegible]of [illegible]clinical study are expected to clarify the i[illegible] of the safety and efficacy of these devices. Total aortic a[illegible]debranching with in situ fenestration has also been documented in case reports.[4-6] Long-term surveillance data of these endografts are not available, and fenestrating an endograft in situ is not without potential pitfalls and loss of integrity in the long term. Similarly, the initial outcomes of chimney grafts have been encouraging,[7] but the long-term durability remains unknown. Until more patients and longer follow-up data are available, chimney grafts should only be considered for emergency patients who are poor candidates for open repair or in the case of preoperative inadvertent coverage of the supra-aortic trunks.

Endovascular treatment of aortic arch aneurysms using branched stent-grafts provides another attractive alternative. An initial experience was reported by Inoue and colleagues[8] in 1999. The device used consisted of a unibody graft with multiple (≤ 3) limbs that were snared and pulled into each of the aortic trunk vessels. The primary success was low (60%), and major complications were caused by multiple cerebral emboli. Chuter and associates[9,10] have described a modular branched stent-graft implanted proximally into the ascending aorta and distally into the innominate artery (IA) and descending thoracic aorta. However, this method has fallen out of favor because of various issues, including delivery of the device through the IA, size constraints, and the relatively high stroke and mortality risk, approaching 30% in anecdotal series.[2] These factors, along with the success achieved in the thoracoabdominal aorta with branched stent-graft repair of thoracoabdominal aneurysms, have led to a refinement in the design and a change in thinking regarding the method of device introduction,

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Abbreviations and Acronyms
CTA = computed tomographic angiography
IA = innominate artery
LCCA = left common carotid artery

resulting in a novel custom-made multibranched stent-graft intended for transfemoral insertion. We report our experience using this new stent-graft for treating aortic arch aneurysms.

METHODS

All the endovascular branched repairs of aortic arch aneurysms performed from October 2009 to May 2011 were reviewed from a prospectively maintained database. All cases were performed under the supervision of 1 surgeon but at different centers (Jewish General Hospital, Montreal; Toronto General Hospital, Toronto; and Vancouver General Hospital, Vancouver). Device approval under Special Access was obtained from Health Canada for each patient. These patients were all deemed to be high risk for conventional surgery by the cardiac surgeons, and, currently, no Health Canada-approved commercially made device is available to treat this anatomy. Full, informed consent was obtained from patients.

Device Design

Procedure planning involved reconstruction of central flow in a 3-dimensional workstation that continues from the ascending aorta into the left ventricle. Study of the proximal anatomy began at the level of the aortic annulus and continued through the origin of the coronary arteries, sinotubular junction, and first part of the ascending aorta. The fundamental concern in the planning procedure involved orientation of the supra-aortic trunk vessels and identification of sufficient sealing zones within the "normal" ascending aorta, each supra-aortic target artery separately, and the descending thoracic aorta.

The branched stent-graft is custom made and manufactured by Cook Medical (Brisbane, Australia) and is loaded into a Flexor sheath with a 20F to 24F diameter. The introducer has an inner nitinol cannula and is precurved. A notch in the modulator tip is aligned with the outer curve of the introducer. The graft is advantage of this novel introducer is that it orients the graft properly during placement into the arch without any rotational maneuvering. In addition, a shorter introducer tip (60 mm) is used; however, with this option, crossing of the aortic valve is inevitable.

The graft is made of polyester and supported by stainless steel-sealing Gianturco Z-stents (Cook Medical) at both ends and a combination of nitinol and stainless steel stents throughout its body (Figure 1, *A*). The use of low-profile polyester has since been introduced to reduce the profile of the device. There are no uncovered stents. The stents are sutured to the inside of the polyester graft at the arterial implantation sites; elsewhere, they are sutured to the outside. The proximal stent has caudally oriented barbs projecting out through the overlying graft to help prevent migration. Thus, the ability to withdraw or advance the device is limited once the sheath has been withdrawn. The graft has a spiral stabilizing wire attaching the graft to the inner cannula at the 12-o'clock position (greater curve line; Figure 1, *A*). It is also attached to the introducer at its proximal and distal ends at a single point on the line of the outer curve. Spiral stabilizing wires, proximal and distal attachments, and diameter-reducing ties have previously been extensively used in construction of fenestrated and branched stent-grafts for treating thoracoabdominal aortic aneurysms.[11,12]

The graft is constructed with 2 side branches. Theoretically, a third branch could be added for the left subclavian artery. Usually, the branch for the left common carotid artery (LCCA) is an 8-mm side branch sited most proximally at the 11:30-o'clock position, and the branch for the IA is a 12-mm branch sited most distally at the 12:30-o'clock position. The first case performed worldwide—in 2009 at McGill University—involved a branched graft with external funnel-shaped branches to facilitate their cannulation (Figure 1, *B*). Concerns were raised about the possibility of compressing these branches onto the greater curvature of the aortic arch, and subsequent cases were performed with branched grafts having fully internal branches with slightly sunken "slit-like" entry points to facilitate their cannulation (Figure 1, *C*). Also, the proximal stent was modified to incorporate the Pro-Form technology (Cook Medical) such that proximal wall apposition was ensured. Gold markers indicate the location of the side branches and the aspect of the graft to be aligned to the greater curve of the arch (Figure 1, *C*). Two sets of gold markers are placed at the branch entries: quadruple linear markers at the proximal edge of the innominate branch and the distal edge of the carotid branch entries and double markers at the distal edge of the innominate branch and the proximal edge of the carotid branch entries. The stent graft tapers at the site of the side-branches to provide more space for branch accommodation. Positioning of double diameter reducing ties further lessens the diameter of the stent-graft at sheath retrieval (Figure 1, *A*).

Bridging from the left common carotid side branch to the LCCA requires a suitable stent-graft (Fluency Plus stent graft; Bard Peripheral Vascular, Tempe, Ariz; or Viabahn; W.L. Gore & Associates, Flagstaff, Ariz), supported by self-expanding stents. Because of the large diameter of the IA, custom-made bridging limbs (Cook Medical) were used from the IA to its branch. These bridging limbs also use "low-profile" fabric and nitinol stents to ensure that the grafts can be loaded into a 14F flexor sheath.

During the course of our series, modifications were made to the deployment system to optimize the accuracy and proximal conformance of the graft. The latest deployment system includes 4 release mechanisms that control wires attaching the graft to the central shaft of the delivery system. The first release removes a spiral stabilizing wire; the second releases the inner proximal attachment; the third releases the proximal diameter reducing ties that give the Pro-Form effect and the outer curvature proximal attachment; and the fourth releases the distal diameter reducing ties and the distal end of the stent graft from the central shaft of the delivery system.

A distal thoracic graft extension was planned when the landing zone was further distal in the descending thoracic aorta. This device was introduced second, achieving overlap of at least 2 stents with the proximal stent-graft.

Device Placement

The first stage of the procedure involved creation of a left carotid–subclavian bypass with occlusion of the proximal left subclavian artery (ligation or placement of a vascular plug). The second stage involved insertion of the branched stent-graft through femoral or aortoiliac access. The procedures were performed in a fixed ceiling-mounted angiosuite for 4 patients and with a mobile C-arm (OEC 9900 Elite; GE Healthcare, Waukesha, Wis) in 2 patients. Initially, a 6F sheath was placed at the origin of the IA through the right axillary artery, which had been surgically exposed. Our preference was an infraclavicular approach. Similarly, a 6F sheath was placed at the origin of the LCCA through the surgically exposed left brachial or axillary artery—depending on the size—and by way of the previously constructed carotid–subclavian bypass. Transfemoral access to the left ventricle through the aortic valve was also achieved using a careful interventional technique, eventually leaving a double-curved, stiff, Lunderquist wire buried in the left ventricle (Cook Inc, Bloomington, Ill). Intravenous heparin was administered to maintain an activated clotting time greater than 250 seconds. The graft was advanced over the stiff wire and confirmed to be in the correct position, with the proximal edge of its fabric lying distal to the coronary ostia and the distal markers of the innominate and carotid branches lying proximal to their respective

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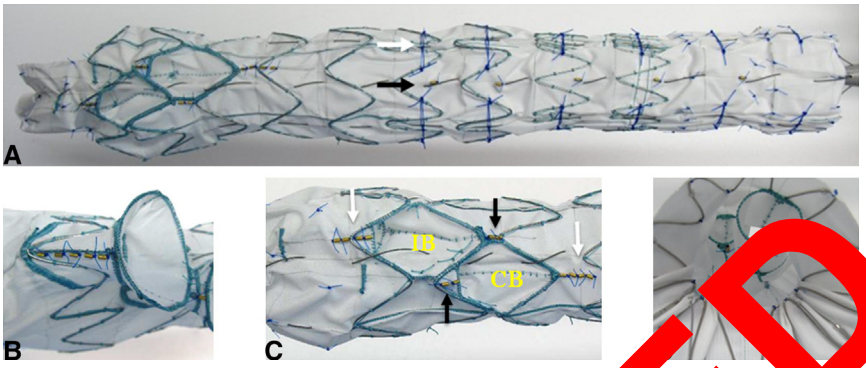

FIGURE 1. A, Stainless steel stent (*white arrow*), spiral stabilizing wire attaching graft to inner ca[illegible]a attach[illegible] graft to [illegible]ula at the 12-o'clock position (*black arrow*). B, Funnel-shaped external components designed at the orifice of the branches to fa[illegible]te t[illegible] cannulation. C, Diamond shaped outer openings, slightly sunken to facilitate cannulation of the innominate (*IB*) and carotid (*CB*) bra[illegible]s. D, [illegible]al low-p[illegible]e side branches.

ostia. At this position, the tapered tip of the device is generally through the valve into the left ventricle (Figure 2).

The deployment sequence has been modified and simplified through the evolution of the stent-graft design. Currently, the sheath is withdrawn com[illegible] pletely to expose the graft under rapid pacing, and then the first 3 relea[illegible] rings are pulled on the control handle to sequentially deploy it. At this poi[illegible] the rapid pacing is discontinued, normal rhythm is restored, and the tapere[illegible] tip of the introducer and the stiff guidewire are removed from the left [illegible]

FIGURE 2. Positioning of the branched stent graft: A double curved stiff Lunderquist guidewire has been placed into the left ventricle. The tapered tip of the graft has been advanced through the aortic valve into the left ventricle. The proximal edge of the branched graft must lie distal to the left coronary artery (*white arrow*) and the right aortocoronary bypass (*black arrow*) (*dotted line*). The marker of the proximal (*yellow arrows*) and distal (*red arrows*) internal branches must lie proximal to the innominate artery and left common carotid artery ostia (in this case common bovine origin). The transparent white arrows indicate the two 6F sheaths placed closed to the origins of the innominate artery and left common carotid artery.

ven[illegible]e. [illegible] branches for [illegible]A and LCCA are then cannulated through the right- an[illegible]-sided sheath, respectively, and the fourth release ring re[illegible]ins in place t[illegible]ain the distal attachment and stabilize the graft. Bridg[illegible]ng of the IA is usu[illegible]y accomplished with a custom-made limb; this can be introduced through the right axillary artery or through a conduit sewn on to it. It usu[illegible]y requires a stiff wire to be placed into the left ventricle for support. A [illegible]ered stent is used to bridge the LCCA, and this can be further [illegible] with a bare self-expanding stent. Direct flow to the IA and [illegible]CA do not cease for any significant period during the procedure.

When a second distal thoracic stent-graft is planned, the introducer of the branched stent-graft is not removed, and the fourth release ring remains in place. The second endograft is inserted through the contralateral femoral artery and advanced into the branched stent-graft, such that at least a 2-stent overlap exists between the 2 devices (additional stent overlap is preferable). The fourth release ring stabilizes the branched stent-graft during advancement of the second distal thoracic extension, preventing any infolding or displacement. With the distal thoracic part in place, deployment of the branched graft is completed and its introducer is removed, followed by deployment and release of the distal stent-graft.

Patient Sample

All treated patients were considered high risk for open surgery. From October 2009 to May 2011, 6 patients were treated with branched endografts (all men; mean age, 73.5 years). Four patients were treated at the Montreal Jewish General Hospital (McGill University), one at Toronto General Hospital (University of Toronto), and one at Vancouver General Hospital (University of British Columbia). All procedures were performed by

TABLE 1. Patient characteristics (n = 6)

Characteristic	Value
Age (y)	73.5 ± 11.9
Male gender	6/6
Smoking	1/6
Diabetes mellitus	1/6
History of CAD	5/6
History of COPD	3/6
History of cancer	2/6
eGFR < 60 mL/min/1.73 m^2	3/6
History of aortic surgery	1/6
ASA score ≥ 4	5/6

Data presented as mean ± standard deviation or number of patients. *CAD*, Coronary artery disease; *COPD*, chronic obstructive pulmonary disease; *eGFR*, estimated glomerular filtration rate; *ASA*, American Society of Anesthesiologists.

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TABLE 2. Morphologic features of ascending aorta and aortic arch

Pt. no.	Aneurysm type	Diameter (cm)	Target vessel origin	Diameter of aorta (cm)		Length of ascending aorta* (cm)	Clock face orientation of LCCA† (°)
				At STJ	At IA		
1	Distal arch/DTA	6.4	Separate	3.9	4.1	8.5	60
2	Aortic arch	6.5	Separate	3.2	3.2	6.7	37
3	Aortic arch	5.7	Bovine	3.7	3.7	6.7	Bovine
4	Aortic arch/saccular	3.2	Bovine	3.1	3.1	6.6	Bovine
5	Distal arch/DTA	6.2	Separate	3.8	3.8	6.7	67
6	Distal arch/DTA	5.6	Separate	3.4	3.7	5.[illegible]	52

Pt. no., Patient number; *STJ*, sinotubular junction; *IA*, innominate artery; *LCCA*, left common carotid artery; *DTA*, descending tho[illegible]orta. *From [illegible]o IA. †IA considered to be at 0°.

a team led by the author (C.Z.A.). The patient characteristics are listed in Table 1. All patients provided fully informed consent. Two patients had aortic arch aneurysms, three had descending thoracic aortic aneurysms involving the distal arch, and one had a saccular aneurysm of the arch adjacent to the origin of the IA (Table 2). All patients had undergone left carotid subclavian bypass with an 8-mm synthetic graft 1 to 2 weeks before the endovascular procedure. The anatomic criteria for the patients to be considered candidates for an endovascular approach are listed in Table 3.

RESULTS

Of the 6 patients, 4 underwent uneventful placement of the prostheses, with successful exclusion of th[illegible]eurysms. One patient developed a type I endoleak [illegible]t w[illegible] managed successfully. Aneurysm exclusion witho[illegible]nd leak was therefore achieved in 5 of th[illegible]atients[illegible]of whom required a secondary procedu[illegible]o exc[illegible]le the [illegible]u-rysm). Of the 12 target vessels, 11 [illegible] succ[illegible]fully ca[illegible]nu-lated and preserved (Table 4). [illegible]1 p[illegible], canna[illegible]ion of the innominate branch wa[illegible]nsuccessf[illegible]and an extra-anatomic bypass was ne[illegible]to perfuse t[illegible]ight carotid and vertebral arteries. The medi[illegible]rocedure time was 330 minutes (range, 26[illegible]60 minutes), [illegible]median fluoroscopy time was 117.5 [illegible]nutes [illegible]nge, 55-170 minutes), and median contrast [illegible]sio[illegible]mount was 215 mL (range, 150-250 mL). The me[illegible]proxi[illegible]diameter of the graft was 40 mm [illegible]38-[illegible]m[illegible], the median distal diameter was [illegible]mm [illegible]nge, 30-[illegible]mm), and the median length of the [illegible]ch[illegible]as 253 mm (range, 231-291 mm). In 4 pa[illegible]s, a distal thoracic part was used.

The pre[illegible]study is the first reported series for this technology, and a di[illegible]ussion of the case-specific difficulties is warranted. Patient 1 had a distal arch aneurysm; however, the arch vessels we[illegible]ery cl[illegible]ly space[illegible], precluding a proximal seal without cove[illegible]e LCC[illegible]and, possibly, the IA. The custom-m[illegible]e branch[illegible]sten[illegible]aft was placed successfully. Postop[illegible]e computed[illegible]ography angiography (CTA) at 6 we[illegible]ks pos[illegible]ratively demonstrated a significant endoleak. S[illegible]bsequent dig[illegible]subtraction angiography confirmed a late filling type Ia endo[illegible]leak due to inadequate apposition of the proximal [illegible]dge of the endograft at the inner curvature of the aortic ar[illegible](bird beak configuration; Figure 3). The patient [illegible]derw[illegible]elective coiling (eight 12-mm Nester embolization co[illegible], Cook Medical) and gluing (Indermil tissue adhesive; Covidien, Mansfield, Mass) of the aortic aneurysm sac by way of retrograde femoral percutaneous access, with catheter entry into the aneurysm sac between the proximal stent and aorta. Intraoperative angiography and postoperative CTA confirmed the presence of the contrast mixed bioglue within the aneurysm sac, with no evidence of obvious ongoing endoleak. The patient refused follow-up CTA after discharge and was later lost to follow-up.

Patients 2, 3, 5, and 6 underwent uneventful placement of the endografts with successful exclusion of the aneurysms. Patient 3 had an innominate origin of the LCCA, and a modification of the orientation of the branches was made to facilitate cannulation of the branches (Figure 4). Cannulation of the left carotid branch was difficult but successful. The predischarge CTA findings showed compression of the stent-grafts placed into the LCCA (9 × 10-mm and 9 × 5-mm Viabahn; W.L. Gore & Associates). This was most certainly caused by crossing of the 2 branches, which resulted in compression of the carotid branch. A balloon expandable stent was inserted (7 × 51-mm Express stent; Boston Scientific, Natick, Mass), with good expansion of the covered stent. This remained patent and the aneurysm remained excluded after 12 months of follow-up. This patient had mild ataxia noted postoperatively that resolved. Postoperative computed tomography of the head demonstrated a right cerebellar infarct. The patient was in atrial fibrillation before surgery, and restoration of anticoagulation was delayed because of postoperative thrombocytopenia. Although the stroke was considered to have been procedure related, a cardiac source of the embolus could not be excluded. The patient recovered fully and was discharged home 10 days postoperatively.

TABLE 3. Anatomic criteria for patients to be considered a candidate for an endovascular approach

Ascending aortic diameter ≤ 38 mm
Proximal and distal landing zones length ≥ 20 mm
IA diameter > 8 mm, LCCA diameter > 6 mm
Acceptable tortuosity of aortic arch, descending thoracic aorta, abdominal aorta, and iliac arteries
Minimal calcification of aortic arch
Diameter of iliac arteries > 8 mm (appropriate for inserting a 24F size delivery system)

IA, Innominate artery; *LCCA*, left common carotid artery.

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TABLE 4. Intraoperative parameters and follow-up data

Pt. no.	Target vessels accessed (n)	Exclusion of aneurysm	Postoperative complications	In-hospital stay (d)	Follow-up (mo)
1	2/2	No; type I endoleak	Renal failure	12	16
2	2/2	Yes	—	8	12
3	2/2	Yes	Minor stroke	9	12
4	½	No	Stroke	15	9
5	2/2	Yes	—	6	6
6	2/2	Yes	Cardiac ischemia, *C difficile* infection		3

Pt. no., Patient number.

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Patient 4 had a saccular aneurysm of the proximal aortic arch, close to the origin of the innominate artery. The ostium of this saccular aneurysm was considered to be quite wide to be treated with coil embolization. The orientation of the branches was modified as a result of attempting to predict a straighter path of access from the supra-aortic vessels into their respective branches (Figure 5). In hindsight, this was a poor choice. Although the carotid branch was easil catheterized, cannulation of the diamond-shaped openi for the innominate branch was not possible, even after pro longed attempts with different combinations of catheters and wires. The small diameter of the aorta at l of the IA (31 mm, the narrowest in this group o patie and modification of the orientation of the branche ed in firm apposition of the entrance of minate anch to the aortic wall and failure to c ulate Transf oral retrograde cannulation of the IA nc versed curve catheter was also atte ted, t gain, propagation of the wire through its op g was not p ible. Additional attempts to cannulate t IA e abandone, because antegrade angiography howed di shed flow in the IA and the arterial wave ms in the right ial artery were clearly reduced. Be se of e length of the procedure at that point, we ele t erminate the procedure and planned to retu the ating m for exclusion of the sac at a later date. Be se both the l oclavian and the right femoral arte were posed, creation of a right femoral–axillary b pass dvoca as the most expedient and simple ocedure t rfi the right carotid and vertebral arte s his patient o had significant comorbidities with ische heart disease and multiple myeloma, developed right ce al stroke with left-sided hemiplegia. However, he had a good recovery and was discharged home 15 days l r. At a second stage, a 16-mm Amplatzer Vascular Plugs (AGA Medical, Golden Valley, Minn) was placed into e IA to occlude the retrograde flow. The patient was clinically well at 6 months of follow-up; however, the CTA findings have continued to demonstrate a blush of contrast in the aneurysm sac, although its size has remained stable.

The postoperative course of patient 6 was complicated by cardiac ischemia and a *Clostridium difficile* infection that prolonged his hospital stay to 48 days. The patient remained clinically well with his aneurysm excluded at 3 months of follow-up.

DISCUSSION

Aneurysms that involve the aortic arch extend more commonly to the ascending and/or descending thoracic aorta, and isolated aortic arch aneurysms represent only 4% of

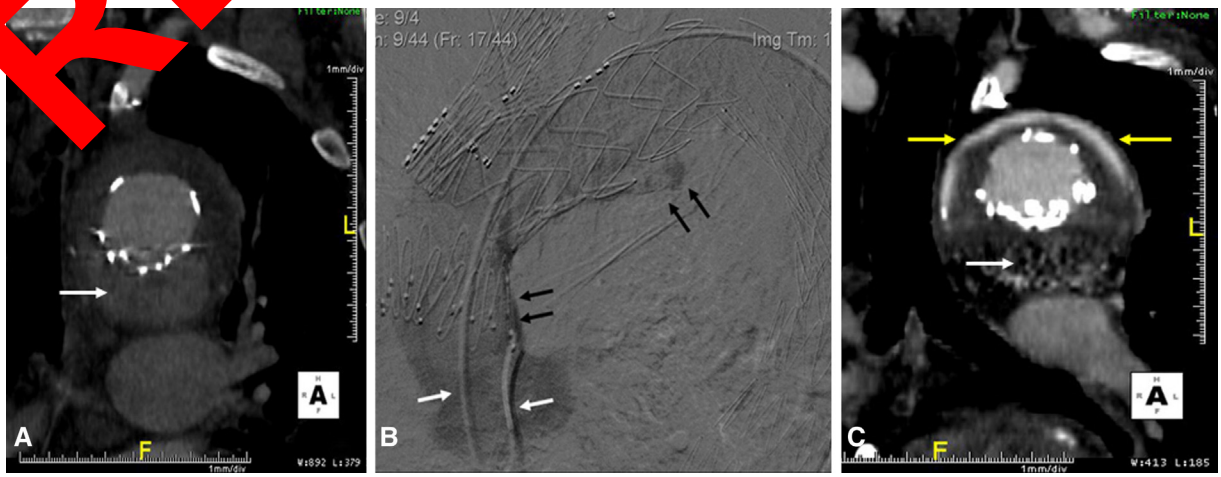

FIGURE 3. A, Computed tomographic angiography type IA endoleak caused by inadequate apposition of the proximal stent to the lesser curve of the ascending aorta shown on digital subtraction angiography (B). Contrast mixed bioglue within the aneurysm sac with no evidence of ongoing endoleak.

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FIGURE [illegible] Standard [illegible]nch [illegible]ion for conventional anatomy of arch aneurysm. B, Three-dimensional reconstruction after branched arch graft. C, Innomi[illegible] orig[illegible]f the le[illegible]on carotid artery, with modification of the branch location to accommodate aberrant arch anatomy. D, Crossing of the 2 bra[illegible]s within[illegible] aberrant a[illegible]tomy, resulting in compression of the carotid branch.

all aortic a[illegible]rysms.[13] The natural history of isolated aortic arch aneurysms is poorly defined, and their surgical treatment requires specific expertise. The endovascular treatment of arch aneurysms using branched stent-grafts that can be introduced transfemorally is appealing for many reasons. This method is minimally invasive and avoids the need to create a carotid–carotid bypass or to insert a bulky component through the innominate bifurcation, which was often an issue with previous modular arch devices. The theoretical, but inherent, risk of disassembly of modular devices is also diminished by the integrated design of the transfemoral branched endografts.

Technical considerations for successful insertion of the device involve transfemoral device delivery or aortic/iliac introduction through an arterial conduit, if necessary. Anomalous arch anatomy, dissections, previous ascending aortic repair, and large-diameter fixation sites will increase the complexity or pose a contraindication to the procedure. Increased tortuosity of the aortic arch can make passage of the device and lining up of the branches difficult. Rotation of the device in the arch is not advised, because this can result in infolding or twisting of the graft. To manage extreme aortic tortuosity, trans-septal techniques with a through and through wire have been described.[14] The characteristics of the IA can make the procedure more challenging because of its large diameter, short length, and, occasionally, tortuosity. The status of the aortic valve is important, because prosthetic or diseased valves are at greater risk of injury

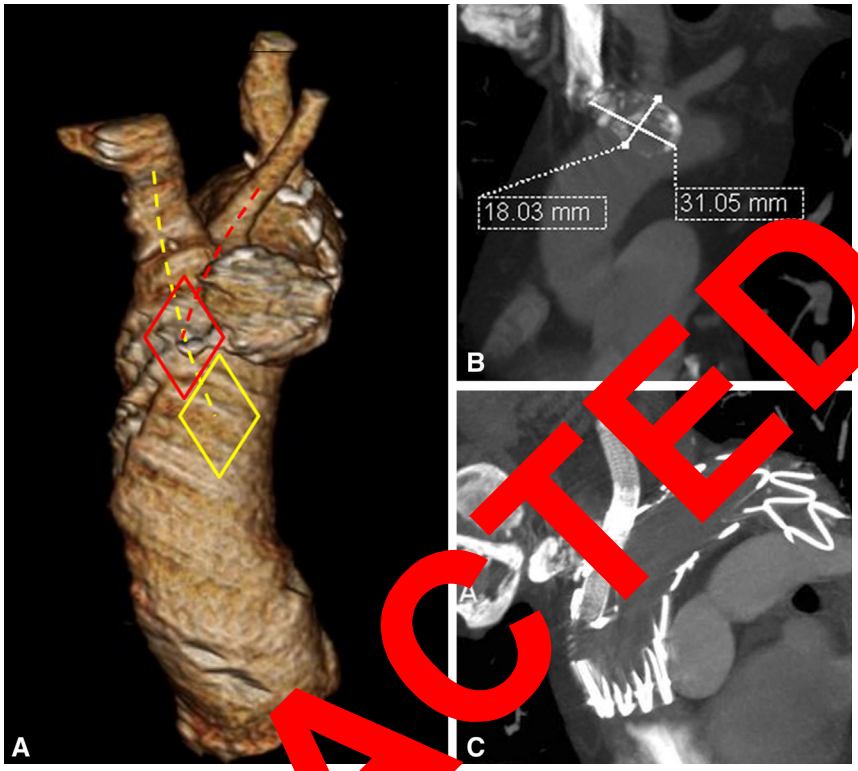

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FIGURE 5. A, Saccular aneurysm of the proximal aortic arch and Innominate artery. Modification of the orientation of branches. B, Size of Innominate artery aneurysm. C, Nonenhanced computed tomography showing left carotid branch.

or might not be amenable to cross with device cone. The use of rapid pacing techniques essential for accurate deployment of the device.

Endovascular occlusion of the proximal left subclavian artery is recommended by using the first-stage procedure to prevent thrombosis of the bypass graft between the stages of the operation from competitive flow. However, others have preferred to defer this to the second-stage procedure to keep endovascular options open for salvage should a problem arise with distal maldeployment of the arch branch graft (personal communication from T. C[illegible]r).

Procedural risks involve injuries to the left ventricle from stiff wire instrumentation and delivery system insertion. Significant challenges exist with respect to the health of the ascending aorta fixation site and the potential for retrograde dissection. This potential complication might be better characterized in the future once more cases have been performed worldwide. The primary concern with this procedure appears to be the potential for stroke (thrombotic/embolic vs low flow). The incidence of stroke in the present series was 2 of 6 cases. Catheter and wire manipulation in the arch are unavoidable, and stroke might prove to be the "Achilles heel" of the procedure. The use of filters to the internal carotid arteries during advancement and deployment of the device into the aortic arch and during cannulation of the branches could theoretically reduce the risk of stroke. However, this addition would increase the complexity of the procedure even more, and protection would be incomplete because the posterior circulation would remain at risk of embolism through the right vertebral artery. Of the 2 patients in our series who experienced a stroke, 1 had a cerebellar infarct.

In the present report, we have demonstrated the technical feasibility of endovascular treatment of aortic arch aneurysms with a simplified branched stent-graft in a small group of patients. With aortic branched stent-grafts, absolute accuracy in the design and placement is necessary. The importance of using a 3-dimensional workstation for planning and a state of the art modern angiosuite for placement of the device cannot be underestimated. Our small series has identified 2 major concerns. The risk of stroke in these patients remains high. Complex arch anatomy could necessitate extensive instrumentation within the arch during positioning of the stent-graft or during cannulation of the branches. Strokes can be embolic or result from inadequate cerebral perfusion, which might have been the case in patient 4. Therefore, hostile anatomy and excessive arch calcification should be considered contraindications for the endovascular approach. An increased case volume and longer follow-up will better characterize this feared complication. Modification of the orientation of the branches—from the usual proximal innominate and distal carotid branch at the 12:30- and 11:30-o'clock position, respectively—proved

unsuccessful in 2 of our patients. Future planning of these procedures must take this potential problem into account.

The long-term durability of the branched stent-grafts in the aortic arch is unknown. Endografts placed in the ascending aorta and the aortic arch are subject to high pulsatile forces that could affect the integrity of their structure. Remodeling of the aortic arch over time could also affect their stability, and the long-term patency of the branches is another concern.

The question regarding the use of these devices for treating type A aortic dissections also remains. Only a few case reports or small series regarding the endovascular treatment of type A dissections using different devices have been reported.[13-17] Two recent studies[15,18] tried to delineate the baseline anatomy of patients with type A dissections and their suitability for endovascular repair. According to these studies, one third to one half of the patients with type A dissection might be suitable for endoluminar repair.[15,18] In general, the primary objectives of endovascular treatment of type A dissections are sealing of the primary fenestration and prevention of retrograde propagation of the dissection. It is possible that these objectives can be accomplished with some type of tubular device landing distal to the sinotubular junction and proximal to the IA or LCCA. In cases in which the entry tear approaches the LCCA ostium, the use of branched aortic arch stent-grafts could be considered. Certainly, several morphologic characteristics must be present to consider such a treatment, and, even then, the applicability of this method is questionable.

Because of the small size of the present series and the short follow-up period, a comparison with reported outcomes for standard open repair or hybrid arch debranching procedures was not possible.[19-24] The results of the present series have demonstrated the technical feasibility of the method. The safety and efficacy will be better defined with longer follow-up and increased worldwide experience. Our initial experience has shown that the method is reliable, and we currently recommend it to high-risk patients with aneurysms involving the aortic arch and suitable anatomy. The need for intervention should be balanced against the risk of complications or death resulting from it.

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